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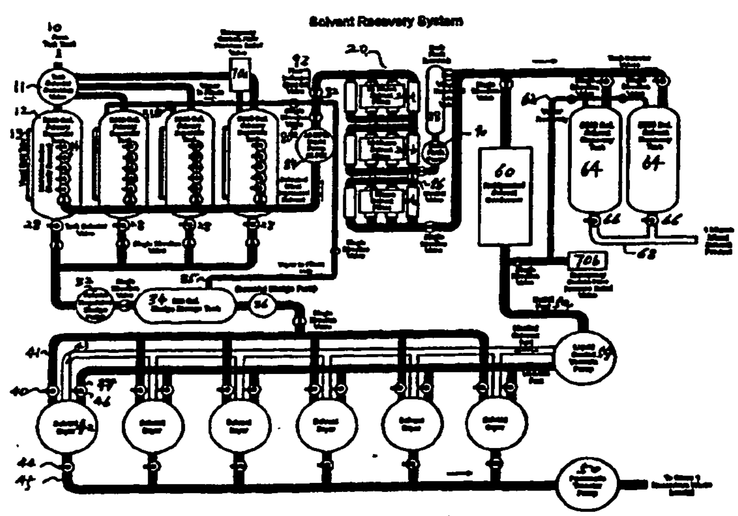

(57) Abstract

The present invention provides a solvent recovery system for recovering volatile organic solvents from substantially water-free industrial liquid wastes and simultaneously clean up remaining solid components from the same wastes so that the converted solvents can be reused by customers and the cleaned solid components are ready to be safely disposed to a landfill under current federal and state regulations. According to the present invention, solvents in the liquid waste are completely recovered and reused. Solid components in the liquid waste are completely cleaned up and basically solvent-free at the end of the treatment. The solvent recovery system of the present invention is able to handle liquid waste with relatively high solid content. The whole system is operated in a closed loop, so that at no point in this process are any solvent vapors exposed to the atmosphere or any operator exposed to any hazardous waste. The only time the waste is exposed to the atmosphere is at the very end of the process when it is completely safe and solvent-free.

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SOLVENT RECOVERY SYSTEM

Background of the Invention

The present invention relates to a system for recovering solvents from industrial liquid waste, and more particularly to a system for recovering volatile organic solvents from substantially water-free industrial liquid waste with relatively high solid content. The present invention also relates to a method for recovering volatile solvents from substantially water-free industrial liquid waste. The present invention further relates to a software design for automatic control of the solvent recovery system of the present invention.

There are many industrial applications where large amounts of organic liquid wastes are generated routinely and those liquid wastes contains large portions of reusable components. More than often, such wastes contain toxic materials which are not allowed to be land filled directly without proper treatment. Therefore, it is environmentally, if not economically, desirable to recover or remove those toxic components from such waste.

U.S. Patent No. 3,361,649 discloses an apparatus and method for the disposal of noxious or toxic aqueous waste material which may be contaminated with material in solution or in suspension. Waste material is introduced into a waste tank and, then, passed through a low temperature vacuum distillation unit in which pure water is removed by condensing on cooling coils. Heavy sludge resulting from the distillation process is passed through a filtering device to remove the liquid material. The liquid is returned for further distillation and sludge concentration at the vacuum still. The waste distillation unit produces a very low solid content in the distillate by evaporation at low temperature and high vacuum.

There are two major disadvantages in the process described in U.S. Patent No. 3,361,649. One of them is that it is not a closed loop process; i.e., vapors of volatile organic solvents are vented directly to the air. This is totally unacceptable under current federal and state regulations. The other is that the remaining solid waste to be disposed is not solvent free, again it is not allowed to bury such solid waste under current regulations. Besides, the process is only applicable to diluted aqueous waste with low solid content.

U.S. Patent No. 5,102,503 teaches a self-contained mobile system for on-site recovery of reusable industrial waste components, such as volatile solvents, by passing a waste stream into a first portion section of a trailer. The stream is then fed in a closed-loop through the evaporator from a second section of the trailer to evaporate volatile solvents in the waste stream, and thereby separating the volatile solvents from non-volatile liquid and solid components of the waste stream. The evaporated solvents are fed to a heat exchanger for recondensation with a coolant. The recondensed solvents are then fed to a water separator tank and molecular sieve tanks for separation of immiscible and miscible water from the solvents. The non-volatile components of the evaporator output are fed to a second holding tank for recirculation through the evaporator and/or return to the customer for disposal.

The method taught by U.S. Patent No. 5,102,503 leaves the remaining nonvolatile liquid and solid components untreated for customer disposal. Apparently, further treatment to the nonvolatile components resulting from this process is needed to meet federal and state regulations for disposal to a landfill. This method cannot treat liquid waste with high solid content efficiently. Besides, this is a batch system which cannot be operated continuously and, therefore, the cost for treating the waste is relatively high.

Incineration is an alternative technology for treating organic hazardous wastes. Although a destruction rate of 99% to 99.99% or even higher can be achieved for target organic compounds, some trace species such as polycyclic aromatic hydrocarbons (PAH) and chlorinated PAH (if chlorine is present) are produced due to incomplete combustion in an incinerator. Those trace species expose high potential risk to human health, although they are produced and emitted at very low concentrations, because some of them are extremely toxic and carcinogenic. Therefore, incineration is not always an acceptable technology for hazardous waste treatment.

In some industries, especially paint industries, liquid waste is generated on a daily basis. Such liquid waste contains volatile organic solvents and relatively high solid content, but is substantially water-free. Those volatile organic solvents are reusable as cleaning solvents and needed by manufacturers in the paint industry. Therefore, there is a need for a method and system which can recover basically 100% of volatile organic solvents from water-free industrial liquid waste in a manner that does not pollute the environment, is easy to handle, and is inexpensive.

Summary of the Invention

One aspect of the present invention is to provide a solvent recovery system for recovering volatile organic solvents from substantially water-free industrial liquid wastes, and simultaneously cleaning up remaining solid components from the same wastes. The converted solvents can be reused by customers and the cleaned solid components are ready to be safely disposed to a landfill under current federal and state regulations. According to the present invention, solvents in the liquid waste are completely recovered and reused. Solid components in the liquid waste are completely cleaned up and basically solvent-free at the end of the treatment. The solvent recovery system of the present invention is able to handle liquid waste with relatively high solid content. The whole system is operated in a closed loop, so that at no point in this process are any solvent vapors exposed to the atmosphere or any operator exposed to any hazardous waste. The only time the waste is exposed to the atmosphere is at the very end of the process when it is completely safe and solvent-free. Because this system can be operated in a continuous way and able to treat large quantities of waste at a high processing rate (more than 5,000 gallons per day), the operating cost per unit waste is relatively low.

According to one aspect of the present invention, it is directed to a solvent recovery system for recovering volatile organic solvents from substantially water-free liquid waste containing volatile organic solvents and solid components. Said solvent recovery system comprises:

a primary separator tank for settling the substantially water-free liquid waste into a liquid phase, a sludge phase and a vapor phase, said primary separator tank having an inlet for receiving said substantially water-free liquid waste, an outlet for said liquid phase, an outlet for said sludge phase, and an outlet for said vapor phase;

a filtering device for removing solid particles larger than a predetermined size from said liquid phase, said filtering device having an inlet and an outlet, said inlet being connected to the outlet of the liquid phase of the primary separator tank;

a solvent recovery tank for containing recovered solvents and vapors of the recovered solvents, said recovery tank having an inlet for receiving the recovered solvents from the outlet of the filtering device, an outlet for said vapors, and an outlet for discharging said recovered solvents;

a solvent dryer for extracting remaining solvents from the sludge phase by vaporizing said remaining solvents, said solvent dryer having an inlet for receiving said sludge phase from the primary separator tank, an inlet for receiving warmed air for controlling temperatures of the dryer, an outlet for discharging dried solvent-free solid components to disposal, and an outlet for vaporized solvents in the dryer;

a vacuum pump for generating vacuum within the solvent dryer and sending the vaporized solvents for condensing treatment;

a solvent condenser for receiving and condensing the solvent vapors from the primary separator tank, the solvent recovery tank and the dryer, said solvent condenser having an outlet connected to the inlet of the solvent recovery tank for sending condensed solvents from said vapors to the solvent recovery tank.

According to another aspect of the present invention, it is directed to a method for recovering volatile organic solvents from substantially water-free liquid waste containing volatile organic solvents and solid components, the method comprises the steps of:

settling said substantially water-free liquid waste into a liquid phase and a sludge phase in a primary separator tank;

pumping said liquid phase to a solvent recovery tank through a filtering device so as to remove particulates larger than a predetermined mesh size from said liquid phase before the liquid phase enters the solvent recovery tank;

pumping the sludge phase from the primary separator tank to a sludge tank;

pumping the sludge phase from the sludge tank to a solvent dryer;

drying the sludge phase in the solvent dryer by evaporating remaining solvents from said sludge phase under a pressure below atmospheric pressure;

providing warmed air to vacuum intake side of the solvent dryer to accelerate the solvent evaporation process;

collecting and condensing all the vapors from the primary separator tank, the solvent recovery tank, the sludge tank, and the solvent dryer with a solvent condenser connected in a closed loop with the primary separator tank, the solvent recovery tank, the sludge tank, and the solvent dryer;

whereby volatile organic solvents are completely separated and recovered from solid components in a closed loop without any solvents or vapors being exposed to the atmosphere or to operators, and the remaining solid components are solvent-free and safe to dispose.

Still another aspect of the present invention is to provide a software design for automatic control of the solvent recovery system of the present invention. In this automatic control system, a PC running the automated

control software of the present invention is used to automatically control the operation of the solvent recovery system.

Brief Description of the Drawings

Fig. 1 is a schematic representation of a preferred embodiment of the solvent recovery system of the present invention;

Fig. 2 is a schematic representation of a solvent dryer used in the present invention;

Fig. 3 is a side view of the solvent dryer of Fig. 2a;

Fig. 4 is a chart showing the automated control software external interfaces of the present invention;

Fig. 5 is chart showing the functional decomposition of the ACS software of the present invention;

Fig. 6 is flow chart of the automated operation high level flow of the ACS software of the present invention;

Fig. 7 is a flow chart showing the decomposed flow diagram of the primary separation tank of the present invention;

Fig. 8 is a flow chart showing a flow diagram of the sludge tank process;

Fig. 9 is a flow chart showing a decomposed flow diagram of the solvent dryer process;

Fig. 10 is a flow chart showing a decomposed flow diagram of the solvent drain process.

Detailed Description of the Preferred Embodiment

The close-loop solvent recovery system of the present invention is designed to recover volatile organic solvents from industrial liquid wastes. Preferably, the liquid waste to be treated is substantially water-free. Typical liquid waste treated with the solvent recovery system of the present invention contains less than 5%, preferably less than 1% of water, and usually contains 40-70% of solvents with the rest being solid components, such as resins and pigments. The recovered solvents are reusable as cleaning solvents in paint manufacturing processes. The remaining solid component at the end of the recovery process are basically solvent-free and safe to dispose. At no point in this recovery process are any solvent vapors exposed to the atmosphere or any operators exposed to any hazardous materials. The only time the waste is exposed to the atmosphere is at the very end of the recovery process when it is safe and basically free from pollutants.

According to the solvent recovery process and system of the present invention, the liquid waste is transported from industrial waste sources to a processing site where the liquid waste is pumped into a primary separator tank and settled for a few days, preferably 3 days, to allow the liquid waste to be separated into two phases under natural gravity. The upper liquid phase contains a small portion of particulate matters and the rest of it is solvents to be recovered. The lower sludge phase contains a large portion of solid components and a small portion of remaining solvents. Then the clear upper liquid phase is pumped through a filtering device to a solvent recovery tank. Particulates larger than certain predetermined size are filtered out by the filtering device, and the filtered liquid phase is ready for shipping to customers and to be reused. The sludge phase at the lower portion of the primary separator tank is pumped to a sludge tank and, from there, is sent to a solvent dryer in a controlled manner. In the solvent dryer, the remaining solvents are evaporated from the sludge phase under vacuum. Warmed air from a liquid sealed vacuum pump exhaust or from an air blower can be introduced into the solvent dryer to

facilitate the evaporation process. The solvent dryer is operated at relatively low temperature which can be controlled by the warmed air, and under vacuum which is generated by a liquid sealed vacuum pump. In a preferred embodiment, the exhaust of the liquid sealed vacuum pump is introduced into the solvent dryer as the warm air source. The liquid sealed vacuum pump is provided with one or more radiation to control the temperature of the exhaust gas before it is introduced into the solvent dryer. Solvent vapors evaporated from primary separator tank, sludge tank, solvent dryer, and solvent recovery tank are gathered together and fed into a solvent condenser. The condensed vapors are pumped to the solvent recovery tank. Solid output from the solvent dryer is pumped to a container such as a R.R. car for disposal.

Referring to Fig. 1 which shows a solvent recovery system of the present invention, a more detailed description of the present invention is given below.

Primary Separator Tank

According to the present invention, liquid waste 10 transported from an industrial waste site is pumped into a primary separator tank 12. A tank selector switching valve 11 is provided at the inlet of the separator tank 12 to select individual separator tank 12. In primary separator tank 12, liquid waste 10 is allowed to settle for a few days (e.g. 3 days) and to separate into two phases. An upper portion of a "clear" liquid phase contains mainly volatile organic solvents to be recovered. A lower portion of a sludge phase contains solid components, such as resin and pigment particles, and a small portion of remaining solvents. A plurality of primary separator tank 12, preferably 2-10, more preferably 3-5, are used depending on the amount of liquid waste 10 to be treated and desired processing capability. The size and shape of primary separator tank 12 may vary. It is usually made of coated steel. If halogenated solvents or other corrosive solvents are present, then stainless steel can be used. In one preferred embodiment of the present invention, four primary separator tanks 12 with a volume of 5000 Gal have been used per line. Primary separator tank 12 is equipped with a visual sight tube 13 made of glass or quartz to monitor the separation interface between the two phases formed after the settling treatment. The visual sight tube 13 can be replaced with other devices, such as a density measuring device, which serves the same purpose like a sight tub,e but can be automated with computer control. Primary separator tank 12 is also equipped with tank selector valve 28 for controlling discharge of the sludge phase. Valve 28 is preferably one direction valve. A series of valve 14 is provided along a vertical direction of primary separator tank 12 to control the amount of the "clear" liquid phase to be pumped to solvent recovery tank 64. The number of valve 14 is determined according to the height of primary separator tank 12. It is desirable to have one valve 14 about every 6 inches along the height of primary separator tank 12. Since in most cases solid content in liquid waste 10 is less than 80%, there is no need to install a valve 14 on the top section. In one preferred embodiment of the present invention, the primary separator tanks 12 are 16 feet tall and a total of 16 valves 14 are installed for each of primary separator tank 12 down from the halfway point thereof, i.e., one approximately every 6".

A vapor bypass 31 is installed to the top of primary separator tank 12. This bypass provides an exit for vapors in primary separator tank 12 and releases the pressure built up in the primary separator tank 12 due to solvent evaporation from ambient temperature change that heats up the liquid sludge. The vapor bypass 31 is

necessary and important for safe operation because this solvent recovery system is a closed system. Too much pressure build-up may cause a serious accident. Thus, to further secure safety of the system, an emergency carbon filter pressure relief valve 70a is provided. The pressure relief valve 70a is connected to the vapor bypass 31 off the separator tank 12. Any solvents trapped in the carbon filter of the pressure relief valve 70a can be removed in the solvent driers 42 of the system. Vapors from the primary separator tanks 12 travels through a single direction valve 80a to a liquid-vapor joint 82. Then the vapors, together with liquid solvent from the upper liquid phase of the primary separator tank 12, are sent to a filtration device 20. In another embodiment, the vapors from the primary separator tank 12 do not go through the liquid-vapor joint 82. In stead, they are bypassed to a solvent condenser 60. In the later case, a filter (not shown) is provided between the vapor bypass 13 and the solvent condenser 60, where any particles larger than a predetermined size will be removed. Preferably, the predetermined particle size is about 1 micron. After being condensed, the condensed vapor is sent to a solvent recovery tank 64.

Filtration Device

The "clear" liquid phase from the primary separator tank 12 and the vapors from the vapor bypass 13 are pumped with a liquid pump 84 to the filtration device 20 through liquid-vapor joint 82 and a flow indicator shut off valve 92. Through filtration device 20 they are filtered to a predetermined mesh size, preferably one micron. Thus, any particles larger than about 1 micron will be filtered out before the "clear" liquid phase and the vapor are sent to the solvent recovery tank 64. Filtration device 20 preferably comprises a plurality of filtering units 24 (a, b, c, ...). Those filtering units 24 are connected to each other in series with decreasing mesh size along downstream direction in the sense of solvent flow, so that larger particles will be filtered out first by upstream filtering units 24 and the finer downstream filtering units 24 are protected from being quickly clogged by large particles. Each filtering unit 24 preferably comprises a plurality of filtering channels connected in parallel, each channel contains a filter of the same mesh size. The mesh size of filtering units 24 of filtration device 20 varies. In one preferred embodiment, three filtering units 24 with a mesh size 30, 10 and 1 micron, respectively, are used. As shown in Fig. 1, a control valve 86 is provided between filtering unit 24c with 1 micron filters and the upstream filtering unit 24, so that filtering unit 24c can be isolated from the rest filtering units 24. Right upstream control valve 86, a back flush reservoir 88 is connected. In another preferred embodiment, filtering units 24 are arranged in a sequence of 30, 25, 20, 15, 10, 5 and 1 micron in terms of their mesh size. Filtration device 20 has a processing capacity of more than 2,500 gallons per hour.

Optionally, each filtering unit 24 may include several independent sections so that the filtering operation can continue even if one or more sections are clogged. A multi-channel valve is installed at the upstream location of each filtering unit 24. The multi-channel valve controls the switching from one filtering channel or filtering section to another, so that plugged filters can be replaced and cleaned up when that channel or section is off-line without interrupting the filtering process.

Used and clogged filters are cleaned and reused. There are several ways of cleaning the clogged filters. The filters in filtering units 24 with a mesh size down to 5 micron used in this invention are usually made of stainless steel. Those filters can be cleaned by back flush. The cleaning is conducted with the solvent from the back flush

reservoir 88. Back flush pump 90 pumps said solvent back through filtering units 24. The filters in filtering units 24 with a mesh size down to 1 micron used in the present invention are usually made of fabric. Those fabric filters need to be cleaned under vacuum in the solvent dryer 42.

Optionally, the cleaning of fabric filters of 1 micron size can be done by incorporating filtering unit 24 and solvent dryer 42 into a close loop. For example, the upstream portion of the filtering unit 24 can connected to the vacuum intake port and the downstream portion can be connected to a warm air source. In this way, no solvent from the contaminated filters is exposed to the atmosphere while cleaning the filters.

Solvent Recovery Tank

The filtered solvents (filtrate) from filtration device 20 are then sent to solvent recovery tank 64, and ready for reuse by customers. Solvent recovery tank 64 can be of any proper size and shape and made of the same materials as the primary separator tank 12. In a preferred embodiment of the present invention, solvent recovery tank 64 has a cylindrical shape and a volume of 5,000 Gal. A discharge valve 66 is installed on the outlet line 68 at the bottom of the solvent recovery tank 64. The recovered solvents in the recovery tank 64 are discharged into a solvent recycler through the outlet line 68 controlled by discharge valve 66. The recovered solvents in the solvent recycler are shipped to customers for reuse.

A vapor bypass 62 is installed to the top portion of the solvent recovery tank 64 and is connected to the inlet at the bottom of the solvent condenser 60 through a through a single direction valve. This provides an exit for solvent vapor inside the solvent recovery tank 64. When pressure builds up in the solvent recovery tank 64 due to ambient temperature changes or sunshine, the solvent vapor travels from the solvent recovery tank 64 back to the entrance of solvent condenser 60 through the single direction valve, which helps to release pressure and prevent accidents (due to high pressure) from happening. A second emergency carbon-filter pressure relief valve 70b is installed to the vapor bypass 62 pipe off the solvent recovery tank 64. Other commonly used safety devices can also be used here to ensure safe operation.

Solvent Condenser

The solvent condenser 60 is provided to condense vapors from solvent recovery tank 64 and solvent dryer 42. Optionally, it also receives vapors from primary separator tank 12 and sludge tank 34. The vapors are condensed and recovered in a closed loop, so that no vapors are vented to the atmosphere during the recovering process. Preferably, the solvent condenser 60 used in the solvent recovery system of the present invention is a coolant-cooled condenser with a processing capacity of 15,000-20,000 gallons per day. In one preferred embodiment of the present invention, water is used as coolant.

Sludge Tank

The sludge from the bottom portion of the primary separator tank 12 is pumped by a volume regulated sludge pump 32 into a sludge storage tank 34 which holds the sludge temporarily. The sludge in the sludge tank 34 is then fed, through a demand sludge pump 36, into individual solvent dryers 42 when needed. In the solvent dryers 42 the sludge is agitated and dried. Sludge tank 34 may have various shape and size. Preferably it has a volume of 300-2,000 Gal, more preferably 500-1,000 Gal, and is made of coated steel. More than one sludge tank

can be used. In one preferred embodiment of the present invention, one sludge tank 34 per line is used and it has a volume of about 500 Gal. Sludge tank 34 is also provided with a vapor bypass 35 connected to its top portion. Vapors from the top portion of the sludge tank 34 travels to liquid-vapor joint 82 through a single direction valve.

Optionally, the vapor can be bypassed to the entrance of solvent condenser 60 through a filter. Particles larger than a predetermined size are filtered out by the filter. Preferably, the predetermined size is about 1 micron.

A centrifugal filter can be optional used before or after the sludge tank 34 to accelerate filtering. A centrifugal filter can also be used prior to the entire process to separate heavy metals.

Solvent Dryer

The sludge from sludge tank 34 is pumped by demand sludge pump 36 into one of a series of solvent dryers 42 as their production cycles permit. Solvent dryer 42 has an inlet 41 for receiving the sludge from sludge tank 34, an inlet 43 for receiving warmed air from the exhaust of a liquid sealed vacuum pump 54, an outlet 45 for dried solid components, and an outlet 47 connected to the liquid sealed vacuum pump 54 for vacuuming dryer 42 and venting solvent vapors to condenser 60. Sludge inlet 41 is controlled by valve 40. Sludge outlet 45 is controlled by valve 44.

Referring to Figs. 2 and 3, each solvent dryer 42 is equipped with a vacuum pressure gauge 49, a solvent vapor present indicator gauge 51, and a temperature gauge 53. If solvent vapor is present above a predetermined level in the solvent dryer 42, the system will continue operating. Since the sludge will vary in composition and consistency, it is necessary to monitor each batch individually. The solvent indicator gauges 51 are validated by actual TCLP soil sample lab tests. A flow quantity meter 104 is provided at sludge inlet 41.

As shown in Figs. 2 and 3, a modified plaster mixer with a series of mixing blades 102 rotating at predetermined speeds, preferably 5-50, more preferably 25-35 RPM, is used as the dryer tank of the solvent dryer 42. The mixing blades 102 of the dryer 42 are tipped with protective layers, preferably with Teflon. The rotating blades 102 constantly refresh the surface of the sludge where the vapors are boiled off. The constant refreshing of the surface ensures that all of the solvents in solvent dryers 42 are exposed and removed. The thin fill line 106 and the center venturi 108 further help with the refreshing of the sludge surface.

Vacuum is pulled into the dryer tank during operation to create a proper vacuum so that the boiling point of the solvents is reduced to ambient temperature or close to that. In other words, pressure in the dryer tank is reduced below or close to the vapor pressure of the solvents at operating temperature. Thus, solvents contained in the sludge are evaporated into gas phase under a thermodynamically favorable condition. Therefore, the operating pressure in the dryer tank is typically below the atmospheric pressure. Depending on capacity of the vacuum pump, the pressure can be reduced to almost any desired value. The temperature of the dryer tank can be controlled by warmed air which is supplied by the exhaust of the liquid sealed vacuum pump 54 or other sources. Preferred operating temperature of the solvent dryer is in the range of about 70-130 F, more preferably 90-110 F. In one preferred embodiment, the vacuum inside the solvent dryer 42 is regulated by running the liquid sealed vacuum pump 54 at an exhaust pressure of about 2 atm (the pressure at the exhaust of the vacuum pump). And the temperature of the exhaust gas from the liquid sealed vacuum pump 54 is adjusted to about 100 F through a radiator or a heat

exchanger (not shown) before the exhaust is introduced into the solvent dryer 42 through inlet 43. It is found that by introducing warmed air into solvent dryer 42, the evaporation process as well as the flow therethrough is greatly promoted.

The number of dryers 42 used in the system of the present invention may vary depending on desired processing capacity. Fig. 2a shows 6 solvent dryers per line. The volume of dryer 42 may vary, preferably from 50 to 150 Gal, more preferably from 80 to 100 Gal. In a preferred embodiment of the present invention, six solvent dryers 42 of volume 94 Gal are used in parallel.

Vapors from solvent dryers 42 are sent to condenser 60 though vapor outlet 47 and the outlet port 52 of the liquid sealed vacuum pump 54. A filter can be optionally installed between outlet port 52 and solvent condenser 60, where particles larger than a predetermined size will be removed. Preferably , the predetermined size is about 1 micron. A number of manufacturers and suppliers use recovered solvents in their manufacturing processes. Valves 46 are provided to control the flow of vapors 52 and/or the vacuum of dryer tanks.

After finishing the drying process, which usually takes several hours, preferably 2-3 hours, the remaining solid waste in solvent dryers 42 is completely solvent-free and ready to be safely land-filled at a Class I hazardous waste site or at a standard waste site. The solid waste is pumped, by a transfer pump 50, from solvent dryers 42 to a roll-off container and shipped to a landfill. The transfer pump 50 pulls out dried solid waste.

Vacuum Pump for the Solvent Dryer

The liquid sealed vacuum pump 54 is employed to provide dryer tanks with required degrees of vacuum. More than one vacuum pump 54 can be used, depending on the amount of sludge to be treated and the capacity of the vacuum pump. Vacuum pump 54 is liquid (oil) sealed so that the pump fins will never wear. This also guarantees a totally closed loop vacuum system with no possibility of solvent vapors being exposed to the atmosphere.

The intake side of the vacuum is warmed to about 80-130, preferably 90-110, more preferably 95-105° F, and pumped into the dryer exhaust tanks to further accelerate the solvent extraction process. In one preferred embodiment, the temperature of the intake side of the vacuum is regulated to about 100° F by a radiator through which the exhaust of the liquid vacuum pump 54 is introduced.

AUTOMATION OF THE SOLVENT RECOVERY SYSTEM

Referring now Figs. 4-10, the following section describes the software design for automatic control of the solvent recovery system of the present invention. The following abbreviations and symbols have been used in the section:

ACS	Automated Control Software
EPA	Environmental Protection Agency
PC	Personal Computer (Intel 8x86 based)
SDD	Software Design Document
SRS	Solvent Recovery System

DSC DSC Environmental

1. Introduction

This Software Design Document (SDD) describes the software design for the Automated Control Software (ACS), used to control the DSC Environmental Solvent Recovery System (SRS). The ACS will automatically control each step in the solvent recovery process, as well as maintain statistical records, generate reports and detect possible malfunctions or maintenance issues with minimal intervention of a human operator. The ACS is database configurable, allowing for easy installation and modification to the SRS.

Application and reference documents include DSC Environmental documents, industry documents and vendor documents.

1.1 DOCUMENT OVERVIEW

This document establishes the preliminary and detailed design for the development of the software components which are a part of the Automated Control Software (ACS). The design specified herein identifies all constraints and standards necessary to ensure proper development of the ACS.

The technical content of this SDS is divided into two major sections:

- The preliminary or top-level function overview of the ACS can be found in section 2. This includes the external interfaces and a description of the computer hardware architecture. Also included are the ACS's primary functional groupings with their relationships and data flows.
- The detailed design of the software is contained in section 3. This section is used to further decompose each functional group described in section 2, using flow diagrams, flow charts, figures, text, tables or any method applicable to describe a functional group.

1.2 ACS OVERVIEW

The ACS is designed to provide automated control of the DSC Environmental Solvent Recovery System (SRS) with minimal human intervention. A control monitor is provided to allow an operator to enter EPA information about the substance that is to be processed and to command the system to accept the substance into the SRS. The actual control and processing of the substance within the SRS is then removed from the hands of the operator and is controlled completely by the ACS.

The ACS will maintain records required by the EPA and will generate statistical reports and other printouts.

The ACS is database configurable. This will allow for easy configuration during installation, maintenance downtime or system modification.

Future enhancements of the ACS may include features such as a manual override of the automated operational control and remote monitoring of the SRS.

The safety and error portion of the ACS will continuously monitor the SRS, recording and reporting system failures and maintenance requirements.

2. Preliminary Design

2.1 ACS ENVIRONMENT

The ACS processes are all physically located on a disk drive. After the PC is turned on, the operating system boots and configure the PC. Once the operating system is running, the system startup script starts the executable processes.

2.1.1 Operating System

The ACS is designed to run on Microsoft Windows 95, a commercial operating system designed to run on the IBM PC or compatible. The processes communicate among themselves using signals, pipes, semaphores, global data modules or direct communication.

2.2 EXTERNAL INTERFACES

The ACS supports interfaces with the SRS via RS-485. This and other interfaces are illustrated in Fig. 4 and discussed in the following subsections.

a2p Interface This is a simple printer interface that allows the ACS to send reports and data to a printer.

h2a Interface The h2a interface is the interface between a human operator and the acs running on a pc. It consists of a standard computer keyboard that allow the operator to enter and request data and a monitor that allows the acs to communicate with the operator.

a2s Interface This RS-485 interface allows the ACS to communicate with the SRS. Using this interface, the ACS can command the SRS to open and close vales, request readings from meters and sensors and control various other aspects of the SRS.

a2t Interface This interface may be a future enhancement. It will allow remote communication with the ACS via telephone lines.

2.3 FUNCTIONAL DECOMPOSITION

The ACS software can be divided into several major functional groups (see Fig. 5). These functional groups, which are made up of one or more software modules, perform independent tasks. Section 2.3.1 describes the interfaces between these functional groups, and section 2.3.2 describes the makeup of each group. The description of each of the databases are outlined in section 3.1.

2.3.1 Interfaces

Fig. 5 depicts the control and data flow from one functional group to another. The interfaces between the functional groups are described in the subparagraphs below.

m2m Interface If the ACS has been enhanced to contain manual operation, this interface simply, the main console functional group passing control to the manual operation functional group. No data is passed along this interface.

m2a Interface This interface is a simple semaphore that allows the main console to start or stop the automated operation functional group. No other data is passed on this interface.

m2c Interface Providing manual operation has been added to ACS, this interface is used to pass requests to the system control logic group, which translates the request into RS-485 messages that are forwarded to the SRS. Replies in the form of data or message ACKs are returned to the manual operation group via this interface also.

a2c Interface This interface is used the same ways a the m2c interface, except it is used to communicate between the automated operation group and the system control logic group.

s2m Interface This interface provides a communication path from the safety and error checking functional group to the main console. This allows the ACS to report to the system console any situation that requires the attention of a human operator.

m2s Interface This link is like the m2m interface. The interface is used to pass control to the system maintenance group. No data is conveyed.

s2s Interface This interface allows the system control logic group to report any faults it encounters to the safety and error checking group. The safety and error checking group can also use this interface to make periodic safety checks on the SRS, via the system control logic group.

db Interface This interface is a semaphore protected disk I/O interface that allows various processes to have access to and update the process database and system database.

2.3.2 Functional Group Definitions

Fig. 5 also depicts each of the functional groups. These functional groups are described in the subparagraphs below.

Main Console The main console functional group is responsible for interfacing with the human operator, keeping records, generating reports, allowing access to other functional groups and maintaining general control of the ACS.

Manual Operation This functional group is a possible future enhancement that will allow a human operator to override the automated operational group and control the SRS manually. This is useful for system debug or system maintenance.

Automated Operation This group is the heart o the ACS and is responsible for automatically controlling the SRS. When activated by the main console, this functional group will scan the process database to determine if any action needs to take place. If any action is needed, messages are sent to the system control logic functional group, which is responsible for communicating the SRS. Once all actions are processed, the automated operation group will sleep for a selected period of time, then wake and repeat the process again. The maximum sleep periods are configurable and are automatically selected by the program, depending upon when the next action is scheduled to take place. All states, times, tags, actions, etc. are saved in a database. This allows for the ACS to recover if a failure requires the PC to restart the ACS.

System Maintenance This functional group allows for the update and modification of the system databases. This is used for tasks such as "telling" the ACS how the SRS is configured, i.e., the number of storage tanks, the state of each major component (empty, failed, down for repair, working, etc.), the RS-485 address of each valve or sensor, etc.

System Control Logic This functional group is responsible for all RS-485 communications between the ACS and the SRS.

Safety and Error Checking This functional group monitors the system and reports problems to the main console, as well as logging the problem in the database.

3. Detailed Design

This section expands upon the information outlined in section 2.3.2 Automated Operation. Fig. 6 shows the highest level flow diagram for the automated operation functional group. Once the automated operation is activated, it will audit the status and perform any necessary task for each of the three main process areas of the SRS: the primary separation tanks, the sludge storage tank and/or the solvent dryers. After each of these processes are complete, including updating the databases, the operation will sleep until it is necessary to repeat the operation again.

Fig. 7 shows a decomposed flow diagram of the Primary Separation Tank process.

The process will start by checking if solvent is currently being drained from one of primary separation tanks. If solvent sis currently being drained and the drain is complete, the process will stop the drain process, update the database and exit to the sludge draining process. If the solvents is currently being drained and the drain is not complete, the process will continue the drain process (see Fig. 10) and exit to the sludge draining process.

If solvent is not currently being drained from any of the separation tanks, then the process will check if any of the separation tanks are ready to be drained (usually after about 3 days of settling). If a tank is ready to be drained, the process will use a series of density sensors to determine which valve to open to drain the solvent. Once the solvent drain process start,s the process will update the database and exit to the sludge draining process.

Once the solvent process portion of the separation process is complete, the status of the sludge draining is checked.

If any separation tank is currently draining sludge and that tank is not yet empty, the process will exit.

If any separation tank is currently draining sludge and that tank is empty, the sludge draining process will terminate, the database will be updated, and the process will exit.

If none of the separation tanks are draining sludge, then the process will check if any tank has sludge ready for draining (the solvent is draining process is complete). If a tank is ready, then the sludge draining process is started, the database is updated, and the process exist.

Fig. 8 refers to the Sludge Storage Tank Flow process. It is the responsibility of this process to ensure that the solvent dryer remain full. If the sludge tank is empty, it has nothing to do except ensure the database knows that sludge is needed.

If the sludge tank is not empty, then it tries to fill any empty solvent dryers.

Once all the dryers are filled or the tank empties, the process will exit.

The Solvent Dryer process is presented in Fig. 9. This process will separate the remaining solvent from the sludge using a series of solvent dryers, aided with the heated exhaust from a vacuum pump that is used to remove any remaining solvent vapor.

The process will first check if any of the dryers are currently being emptied of dry waste by the transfer pump. If any dryer is currently being emptied and has now become empty, then the empty process is terminated and the database is updated. If any dryer is currently being emptied and the empty process is not complete, then the empty process will continue and the solvent dryer process will exit.

If none of the dryers are being emptied, then the process will check if any of the dryers finished drying, cooled down and are ready to be emptied. If one is ready, then the dryer is opened, the transfer pump is activated, and the database is updated.

Before the solvent dryer process exits, it will check the solvent detectors in each of the dryers currently in the drying phase. Any dryer free of solvent is stopped and allowed to cool down in preparation for the waste emptying phase. The database is updated and the process exits.

Fig. 10 details the Solvent Drain process referred to in Fig. 7. During a solvent drain from the primary separator tanks, this process will first check if the system is currently being backflushed. If the system is currently in a backflush phase and the backflush is complete, then normal solvent draining is resumed, the database is updated and the process exits.

If the system is currently backflushing and the backflush is not complete, then the process updates the database and exits.

If the system is not back flushing and solvent is being drained, the process will check a solvent flow meter to determine if the solvent filters are clogged and need to be backflushed. If backflushing is needed, the backflush process is started and the solvent drain is stopped. The database is updated and the process exits.

WHAT IS CLAIMED IS:

1. A system for recovering volatile organic solvents from substantially water-free liquid waste containing volatile organic solvents and solid components, comprising:

a primary separator tank for settling the substantially water-free liquid waste into a liquid phase, a sludge phase and a vapor phase, said primary separator tank having an inlet for receiving said substantially water-free liquid waste, an outlet for said liquid phase, an outlet for said sludge phase, and an outlet for said vapor phase;

a filtering device for removing solid particles larger than a predetermined size from said liquid phase, said filtering device having an inlet and an outlet, said inlet being connected to the outlet of the liquid phase of the primary separator tank;

a solvent recovery tank for containing recovered solvents and vapors of the recovered solvents, said recovery tank having an inlet for receiving the recovered solvents from the outlet of the filtering device, an outlet for said vapors, and an outlet for discharging said recovered solvents;

a solvent dryer for extracting remaining solvents from the sludge phase by vaporizing said remaining solvents, said solvent dryer having an inlet for receiving said sludge phase from the primary separator tank, an outlet for discharging dried solvent-free solid components to disposal, and an outlet for vaporized solvents in the dryer;

a vacuum pump for generating vacuum within the solvent dryer and sending the vaporized solvents for condensing treatment;

a solvent condenser for receiving and condensing the solvent vapors from the solvent recovery tank and the dryer, said solvent condenser having an outlet connected to the inlet of the solvent recovery tank for sending condensed solvents from said vapors to the solvent recovery tank;

whereby volatile organic solvents are completely separated and recovered from solid components in a closed loop without any solvents or vapors being exposed to the atmosphere or to operators, and the remaining solid components are solvent-free and safe to dispose.

2. The system of claim 1, further comprising a sludge tank for holding the sludge from the primary separator tank, said sludge tank having an inlet for receiving the sludge, an outlet for sending the sludge to the solvent dryer, and an outlet for vapors to travel to said filtering device, and said sludge tank being installed between the outlet for the sludge phase of the primary separator tank and the inlet of the solvent dryer for receiving the sludge phase.

3. The system of claim 1, wherein said primary separator tank has a plurality of valves arranged vertically along the height of the separator tank for draining the liquid phase inside the separator tank at different heights of said primary separator tank.

4. The system of claim 3, wherein said primary separator tank has a glass sight tube for monitoring interface levels between the liquid phase and the sludge phase.

5. The system of claim 3, wherein said primary separator tank has a plurality of density sensors arranged vertically along the height of the separator tank for measuring densities of the liquid phase and the sludge phase at different height, whereby monitoring interface levels between the liquid phase and the sludge phase.

6. The system of claim 1, wherein the filtration device comprises a series of filtering units with different mesh sizes.

7. The system of claim 6, wherein three said filtering units with a mesh size 30, 10 and 1 micron, respectively, are connected to each other in series with a reducing mesh size downstream.

8. The system of claim 1, wherein the solvent dryer has another inlet for receiving warmed air.

9. The system of claim 8, wherein the warmed air is provided by the exhaust of the vacuum pump.

10. The system of claim 9, further comprising a radiator for adjusting the temperature of the exhaust of the vacuum pump, said radiator being installed between the warmed air inlet of the solvent dryer and the exhaust of the vacuum pump.

11. The system of claim 1, wherein the solvent condenser is water-cooled.

12. The system of claim 1, wherein the vacuum pump is liquid-sealed.

13. The system of claim 1, wherein the dryer is operated at a temperature of 90-110° F and under a pressure below the atmospheric pressure.

14. the system of claim 1, wherein said predetermined particle size is 1 micron.

15. the system of claim 1, wherein the substantially water-free liquid waste contains less than 5% of water.

16. the system of claim 1, wherein the substantially water-free liquid waste contains less than 1% of water.

17. A method for recovering volatile organic solvents from substantially water-free liquid waste containing volatile organic solvents and solid components, comprising the steps:

settling said substantially water-free liquid waste into a liquid phase and a sludge phase in a primary separator tank;

pumping said liquid phase to a solvent recovery tank through a filtering device so as to remove particulates larger than a predetermined mesh size from said liquid phase before the liquid phase enters the solvent recovery tank;

pumping the sludge phase from the primary separator tank to a sludge tank;

pumping the sludge phase from the sludge tank to a solvent dryer;

drying the sludge phase in the solvent dryer by evaporating remaining solvents from said sludge phase under a pressure below atmospheric pressure;

providing warmed air to vacuum intake side of the solvent dryer to accelerate the solvent evaporation process;

collecting and condensing all the vapors from the primary separator tank, the solvent recovery tank, the sludge tank, and the solvent dryer with a solvent condenser connected in a closed loop with the primary separator tank, the solvent recovery tank, the sludge tank, and the solvent dryer;

whereby volatile organic solvents are completely separated and recovered from solid components in a closed loop without any solvents or vapors being exposed to the atmosphere or to operators, and the remaining solid components are solvent-free and safe to dispose.

18. The method of claim 17, further comprising a step of treating the sludge with a centrifugal filter prior to the step of pumping the sludge to the sludge tank.

19. The method of claim 17, wherein in the filtering step the predetermined particle size is 1 micron.

20. The method of claim 17, wherein all the steps are automatically controlled by a computer system.

21. The system of claim 1, further comprising a computer control system for receiving data from various parts of the system and controlling the operation of the system.

Fig. 1

Solvent Recovery System

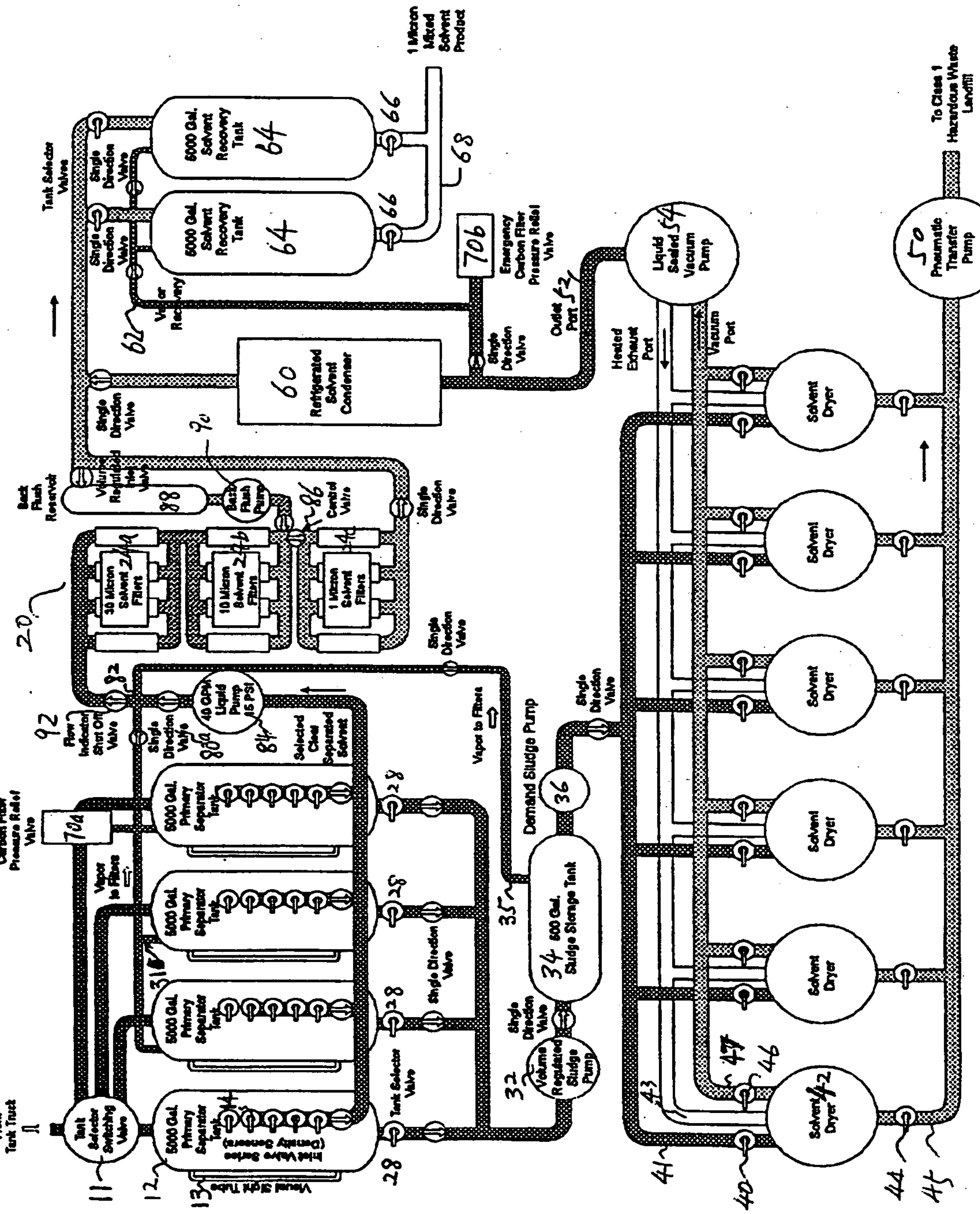


Fig 3

Specifications:
1. Liquid surface area is 4416 sq. inches (1.515 sq. meters).
2. Dryer liquid volume is 94 gallons.
3. Material is coated steel 1/2" to 3/8" thick

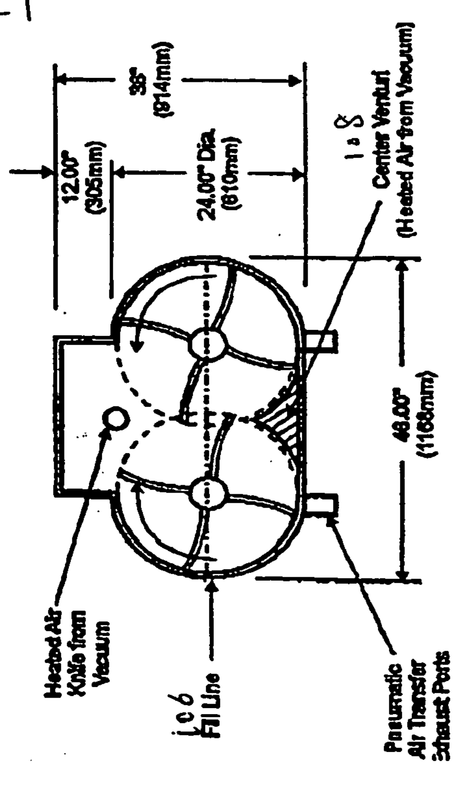
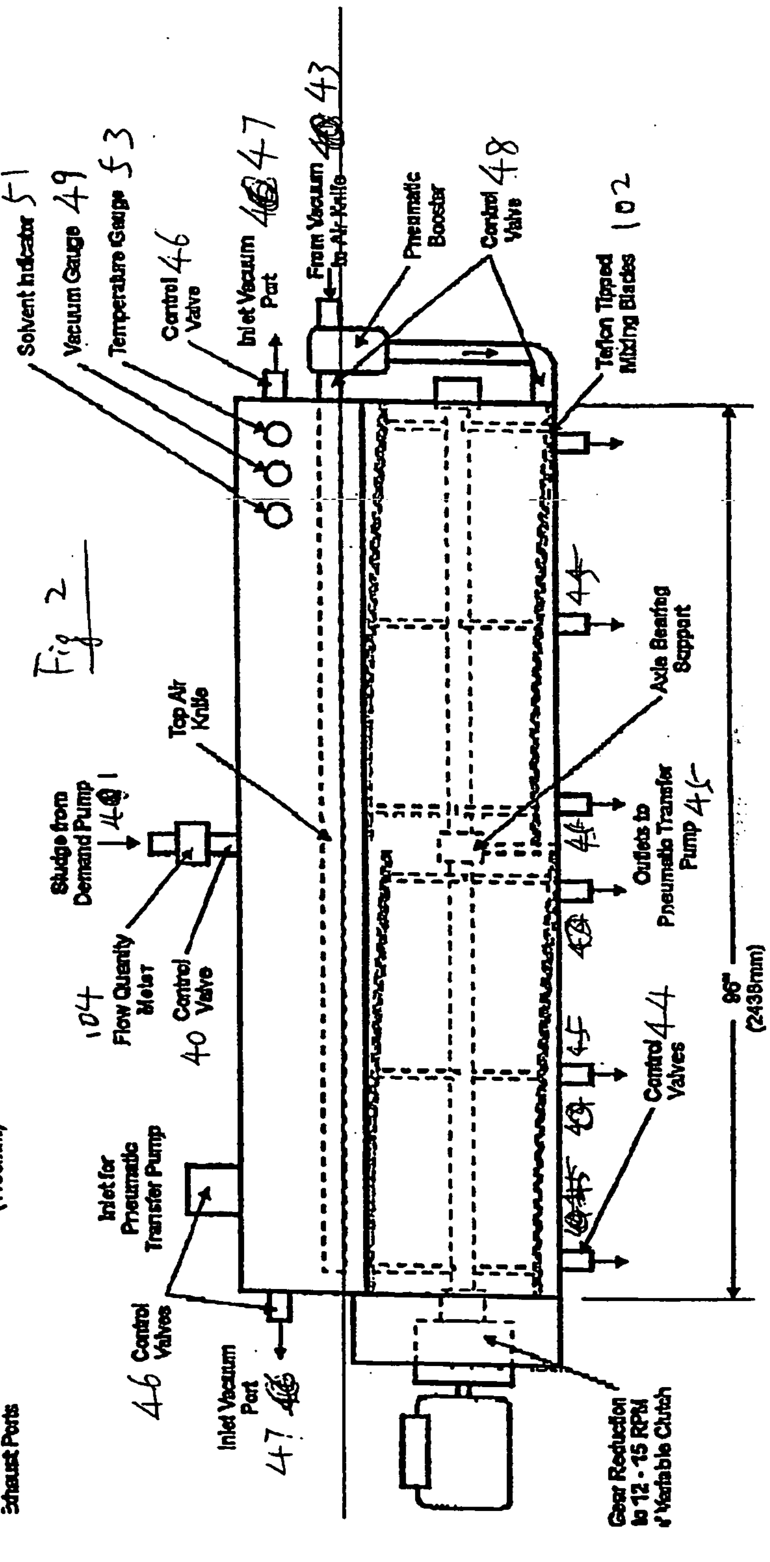


Fig 2



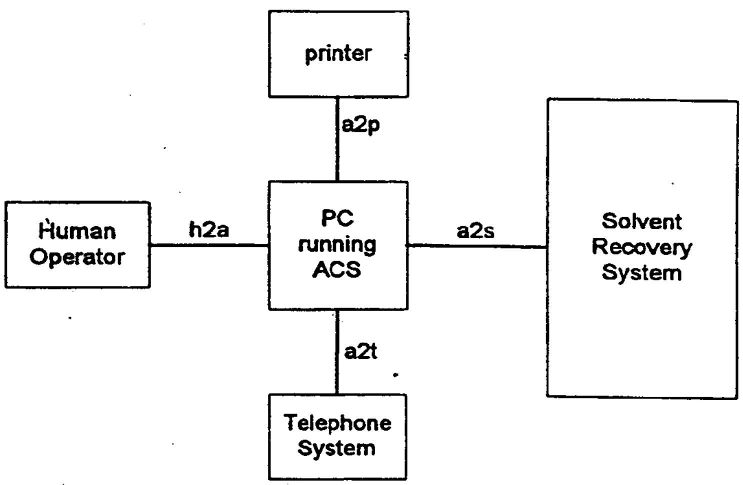


FIGURE 4 - ACS EXTERNAL INTERFACES

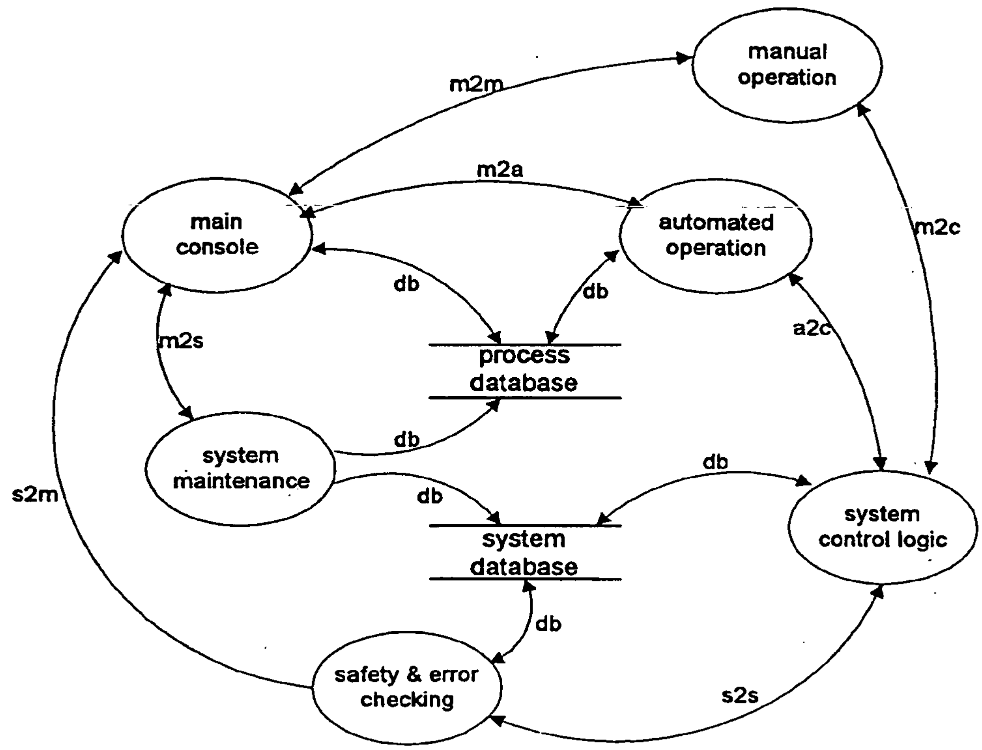


FIGURE 5- FUNCTIONAL DECOMPOSITION

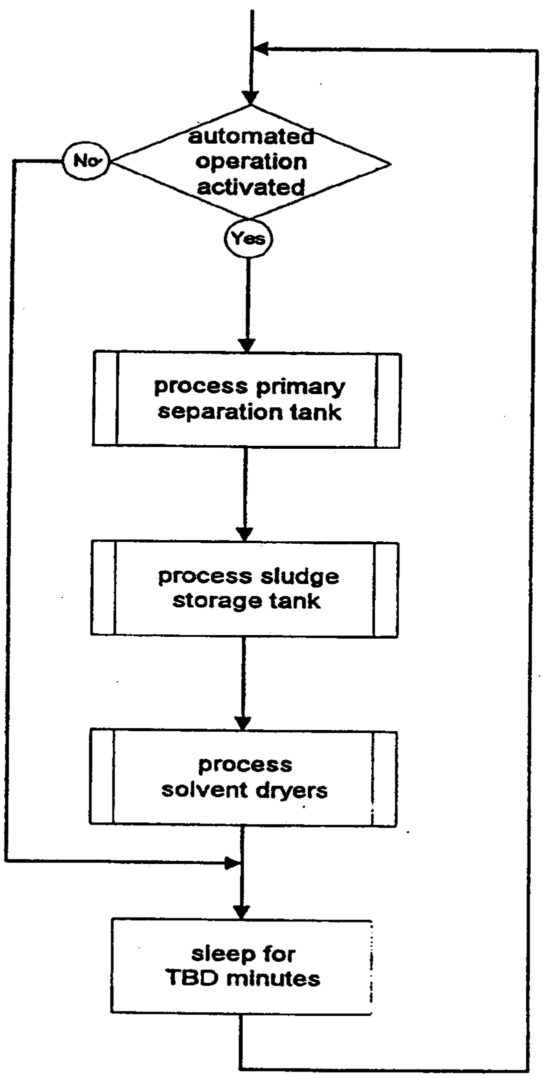


FIGURE 6 AUTOMATED OPERATION HIGH LEVEL FLOW

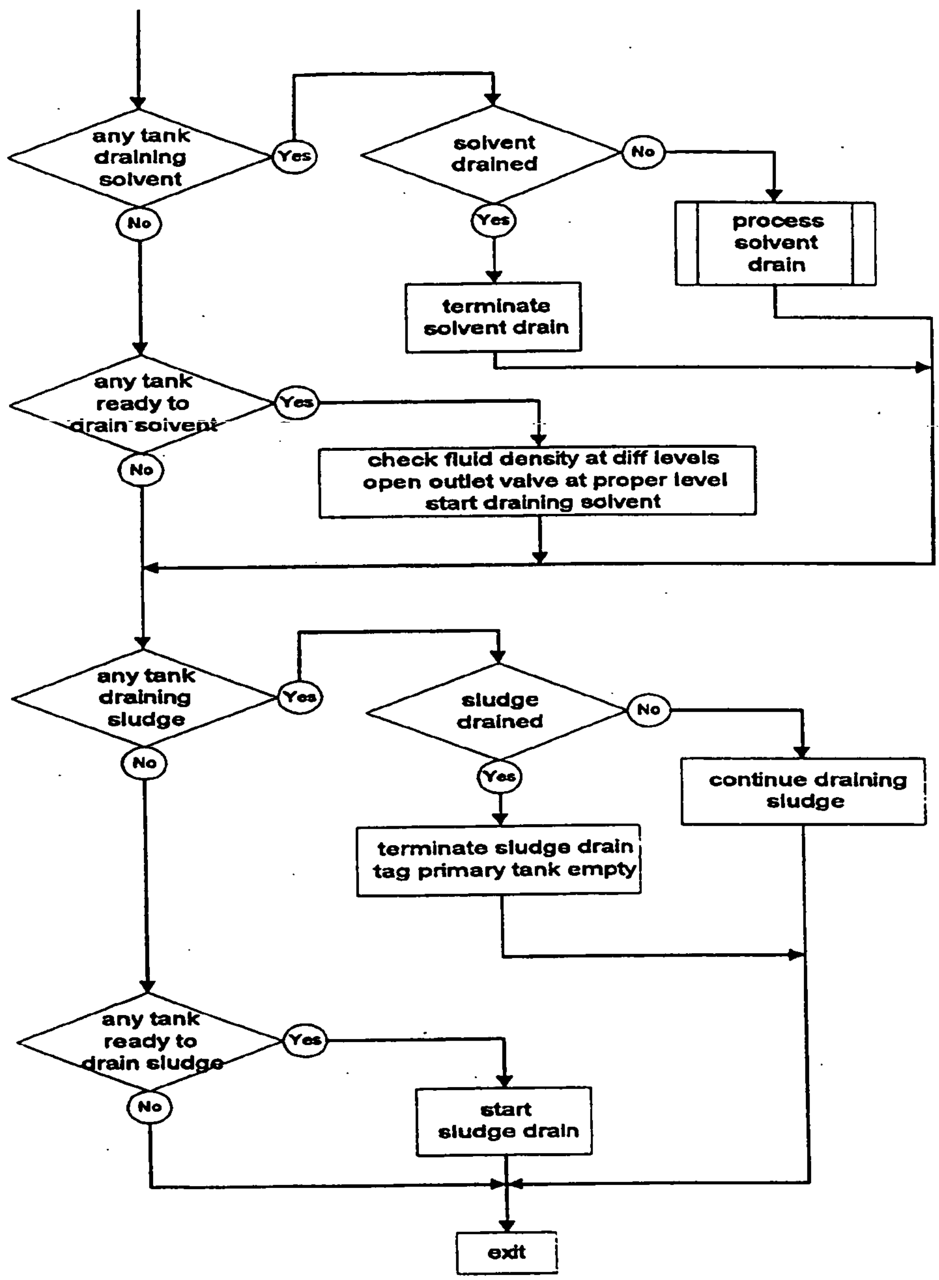


FIGURE 7 - PROCESS PRIMARY SEPARATION TANK FLOW

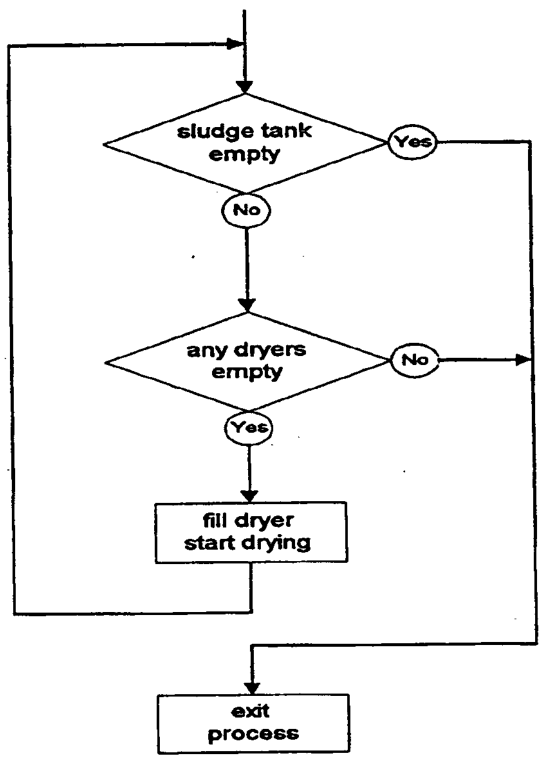


FIGURE 8 - PROCESS SLUDGE STORAGE TANK FLOW

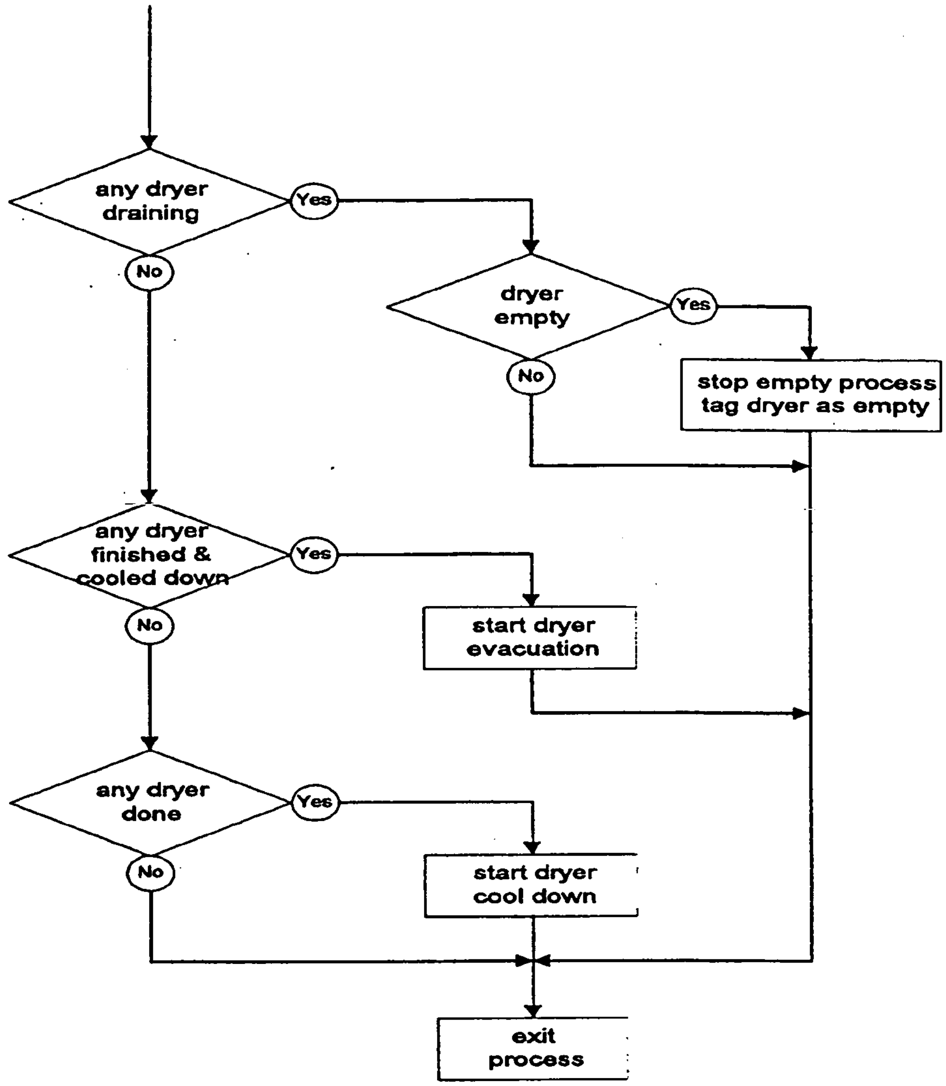


FIGURE 9 - PROCESS SOLVENT DRYERS FLOW

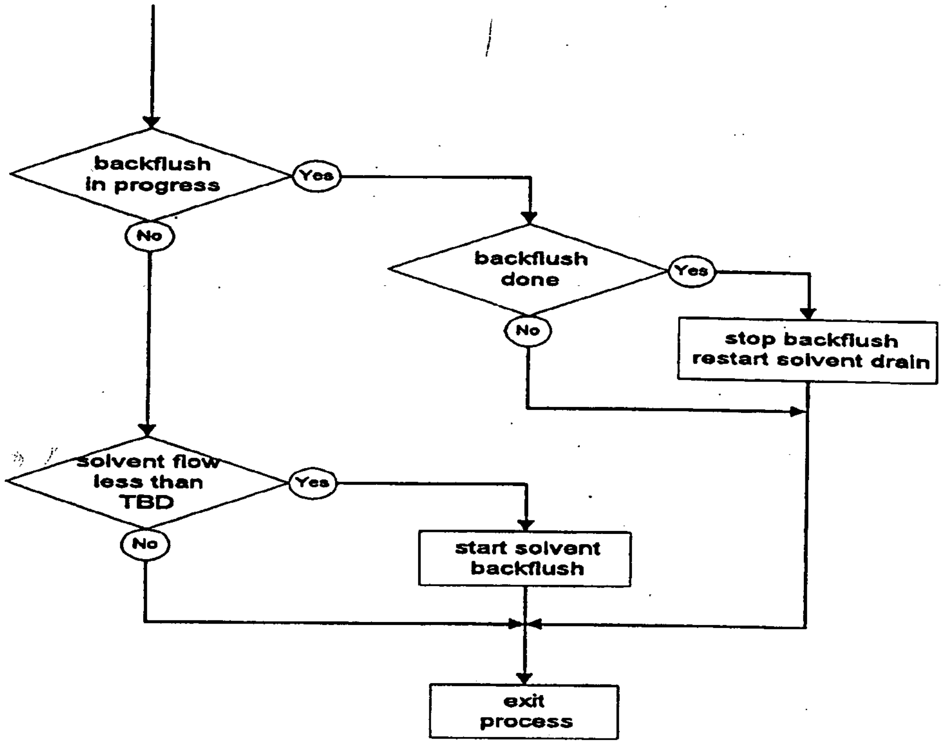


FIGURE 10 - PROCESS SOLVENT DRAIN FLOW